

Submitted to:

National Aeronautics and Space Administration  
Marshall Space Flight Center  
MSFC, AL 35812

Attention: Contracting Officer's Technical Representative, K. Y. Ogle (1 copy)  
Mail Code: ED62  
Mail Code AP29-Q (1 copy)  
Mail Code ER41/Stinson (1 copy)  
NASA Center for Aerospace Information (2 copies)

TR-1619-1-2

TECHNICAL PROGRESS REPORT

Integrated Oxygen Recovery System

Technical Progress Report No. 2

Prepared Under

Program No. 1650

for

Contract NAS8-39843

Contact: R. J. Davenport, Ph.D.

Telephone: (216) 464-3291

May 7, 1993

*IN-54-CR*  
*160779*  
*P.22*

N93-26088

Unclass

G3/54 0160779

(NASA-CR-192982) INTEGRATED OXYGEN  
RECOVERY SYSTEM Technical Progress  
Report No. 2, 9 Mar. - 7 May 1993  
(Life Systems) 22 p

## TABLE OF CONTENTS

	<u>PAGE</u>
LIST OF FIGURES .....	ii
LIST OF TABLES .....	ii
LIST OF ACRONYMS .....	ii
1.0 WORK PERFORMED DURING REPORTING PERIOD .....	1-1
1.1 Assembly of the Breadboard IORS .....	1-1
1.2 Checkout and Shakedown Testing .....	1-5
1.3 Parametric Testing .....	1-8
1.3.1 Temperature .....	1-8
1.3.2 Reactant Gas Composition .....	1-8
1.3.3 Reactant Gas Flow Rate .....	1-13
2.0 PROBLEMS .....	2-1
3.0 WORK TO BE PERFORMED NEXT REPORTING PERIOD .....	3-1
4.0 COST STATUS .....	4-1

## LIST OF FIGURES

<u>FIGURE</u>		<u>PAGE</u>
1-1	Breadboard IORS Cell . . . . .	1-2
1-2	Breadboard IORS Test Setup Mechanical Schematic . . . . .	1-3
1-3	Breadboard IORS Test Setup Mechanical Schematic (Legend) . . . . .	1-4
1-4	Voltage as a Function of Current Density . . . . .	1-6
1-5	Hydrogen Transfer Characterization . . . . .	1-7
1-6	Effect of Temperature on Electrolysis Voltage . . . . .	1-9
1-7	Comparison of Measured and Calculated Conversion Efficiencies . . .	1-11
1-8	Effect of Temperature on Methanation Efficiency . . . . .	1-12
1-9	Effect of Reactant Gas Composition on Methanation Efficiency . . . .	1-14
1-10	Effect of Inlet CO <sub>2</sub> Flow Rate on Methanation Efficiency . . . . .	1-15

## LIST OF TABLES

<u>TABLE</u>		<u>PAGE</u>
1-1	Data for Comparison of Measured and Calculated Conversion Efficiencies . . . . .	1-10

## LIST OF ACRONYMS

CR <sub>2</sub> A	Carbon Dioxide Reduction Assembly
IO <sub>2</sub> S	Integrated Oxygen Recovery System
O <sub>2</sub> A	Oxygen Generation Assembly
PEEK	Polyetheretherkeytone
SBIR	Small Business Innovation Research
SMC	Solid Metal Cathode

## 1.0 WORK PERFORMED DURING REPORTING PERIOD

This Technical Progress Report summarizes the work performed under Contract No. NAS8-39843 from 03/09/93 through 05/07/93. This contract is a Phase I Small Business Innovation Research (SBIR) program to demonstrate the feasibility of the Integrated Oxygen Recovery System (IORS). The IORS is applicable to advanced mission air revitalization. It provides the capability for electrochemically generating metabolic oxygen ( $O_2$ ) and recovering  $O_2$  from the space habitat atmosphere via a carbon dioxide ( $CO_2$ ) reduction process within a single assembly. To achieve this capability, the IORS utilizes a novel Solid Metal Cathode (SMC) water electrolysis unit that simultaneously serves as the Sabatier  $CO_2$  reduction reactor.

The IORS would enable two major life support systems currently baselined in closed loop air revitalization systems to be combined into one smaller, less complex system. It would reduce fluidic and electrical interface requirements and eliminate a hydrogen ( $H_2$ ) interface. Furthermore, since the IORS utilizes an SMC, the system has the additional capability to generate high pressure  $O_2$  (i.e.,  $\approx 1,000$  psia) for recharging extravehicular activity  $O_2$  bottles. This capability is not part of currently baselined or planned technologies.

During this Phase I SBIR program we will evaluate the IORS process by demonstrating its performance and quantifying key system physical characteristics, including power, weight and volume.

Work performed during this reporting period included completion of the assembly of the Breadboard IORS, checkout and shakedown testing of it and its test setup, and the initial parametric testing.

### 1.1 Assembly of the Breadboard IORS

Upon receipt of the polyetheretherketone (PEEK) to be used to construct the cap of the Breadboard IORS (Figure 1-1), the cap was fabricated. The Breadboard IORS was then assembled as described in the previous Bimonthly Technical Progress Report (TR-1619-1-1). It was integrated in the test setup (Figure 1-2, with legend in Figure 1-3).

A reference electrode, not shown in Figure 1-1, was fabricated and mounted in the Breadboard IORS. The electrode is a palladium/silver (Pd/Ag) tube, sealed at one end, and it has a geometric surface area of  $10.1\text{ cm}^2$ . It is inserted in the electrolyte adjacent to the anode. Prior to operation of the Breadboard IORS, the reference electrode is charged with hydrogen by applying a cathodic current of 0.87 A for 12 minutes. Thereafter, no current is applied to the reference electrode, and it provides a virtually stable reference potential that can be used to measure changes in the potential of the anode or cathode.

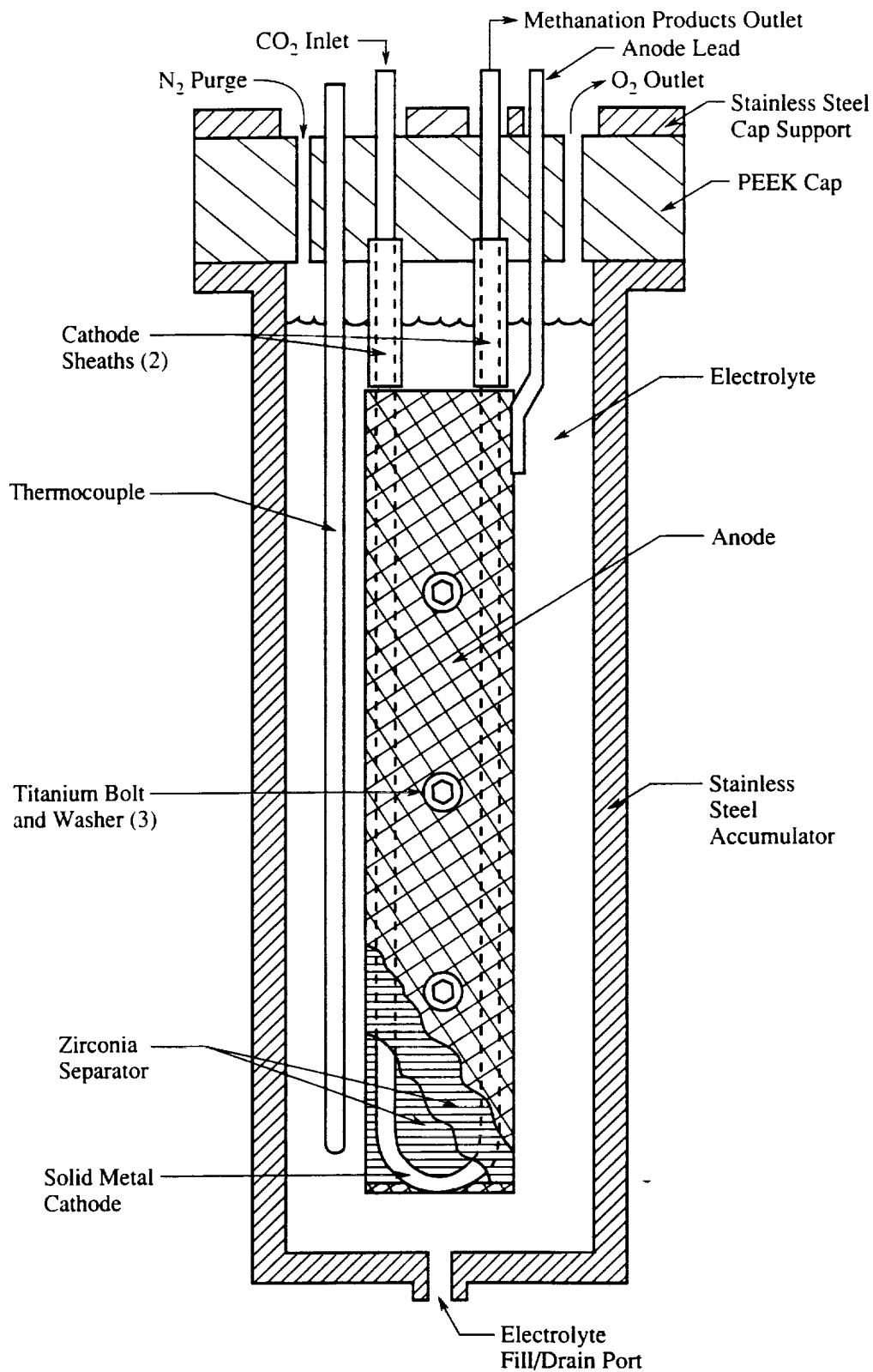


FIGURE 1-1 BREADBOARD IORS CELL

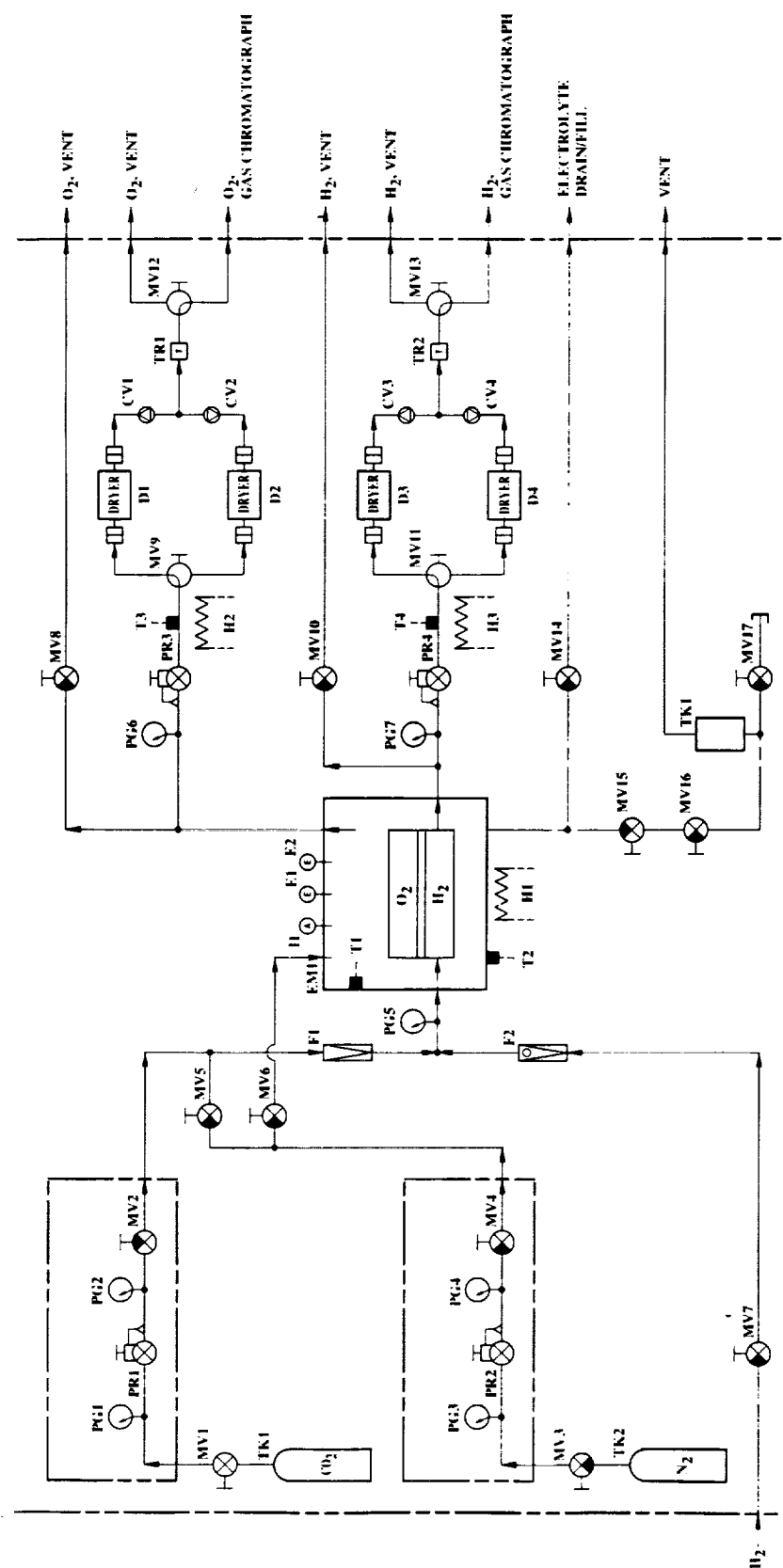


FIGURE 1-2 BREADBOARD IORS TEST SETUP MECHANICAL SCHEMATIC

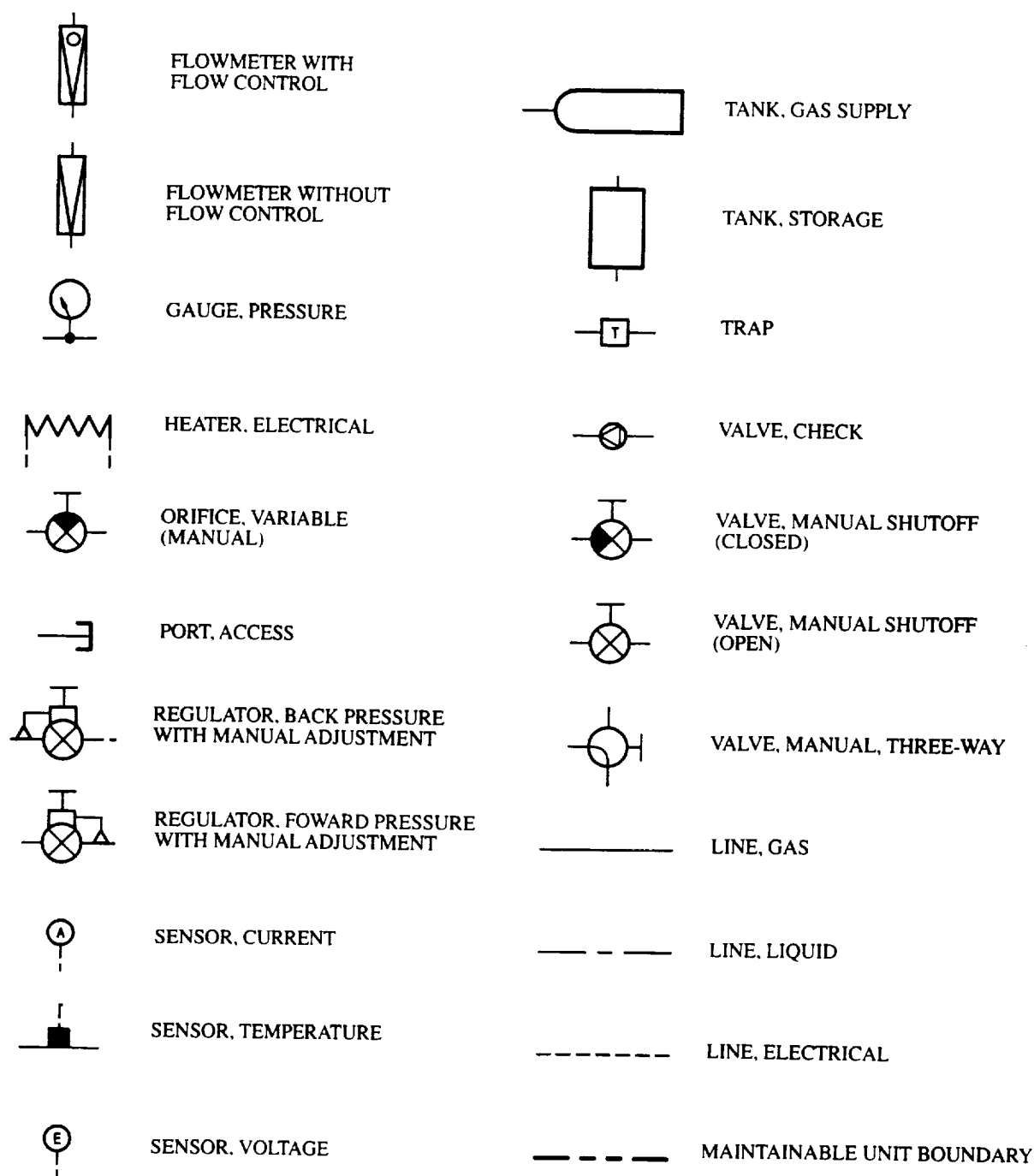


FIGURE 1-3 BREADBOARD IORS TEST SETUP  
MECHANICAL SCHEMATIC (LEGEND)

The gas chromatograph to be used for analysis of the product gases was also setup and calibrated during this reporting period.

## 1.2 Checkout and Shakedown Testing

These tests were performed to verify the integrity of the Breadboard IORS and its test setup. The tests were performed by operating the Breadboard IORS as an electrolyzer, without the methanation catalyst in the cathode.

During these tests it was found that the stainless steel accumulator was oxidized at 140 C, where it contacted the electrolyte (55% potassium hydroxide (KOH)). To avoid oxidation products from contaminating the electrodes, a Teflon cup was fabricated and inserted in the accumulator to hold the electrolyte.

During these tests it was also determined that the titanium nuts, bolts and washers (Figure 1-1) used to hold the anode against the separator and cathode also oxidized. These items were removed and replaced with nickel wire retainers that performed the same function.

After these changes, a new anode, cathode and separator were fabricated and mounted in the Breadboard IORS. No further oxidation products were detected in the electrolyte or on the electrodes. However, the zirconia cloth used as the separator tended to be torn where the anode and cathode were compressed against it. This occurred after six to ten hours of testing, and is attributed to the relatively low mechanical strength of the zirconia cloth when it is wet, compounded by the fact that the cathode expands and contracts as it absorbs and desorbs hydrogen.

The zirconia cloth was replaced with zirconia felt (0.127 cm thick). Further, the felt separator is replaced each time the Breadboard IORS is disassembled for electrolyte replenishment.

The electrochemical performance of the Breadboard IORS at 140 C is shown in Figure 1-4. The terminal voltage and the cathode-to-reference electrode potential is shown as a function of current density over the range of 45 to 200 mA/cm<sup>2</sup>. These data show that the cell potential is relatively low, and that there is little increase in the potential of the cathode, even at the relatively high current density of 200 mA/cm<sup>2</sup>.

Figure 1-5 shows the performance of the SMC in transferring H<sub>2</sub> from its exterior to the interior of the SMC. The Breadboard IORS can produce H<sub>2</sub> at a flow rate of more than 51 scc/min, with a transfer efficiency of 96% or greater, and a power consumption of only 13.5 W at 140 C.

Methanation of CO<sub>2</sub> in the SMC does not occur in the absence of catalyst. Prior to installation of catalyst in the Breadboard IORS, it was operated at a current density of 200 mA/cm<sup>2</sup> at a temperature of 143 C, with CO<sub>2</sub> flowing through the SMC at



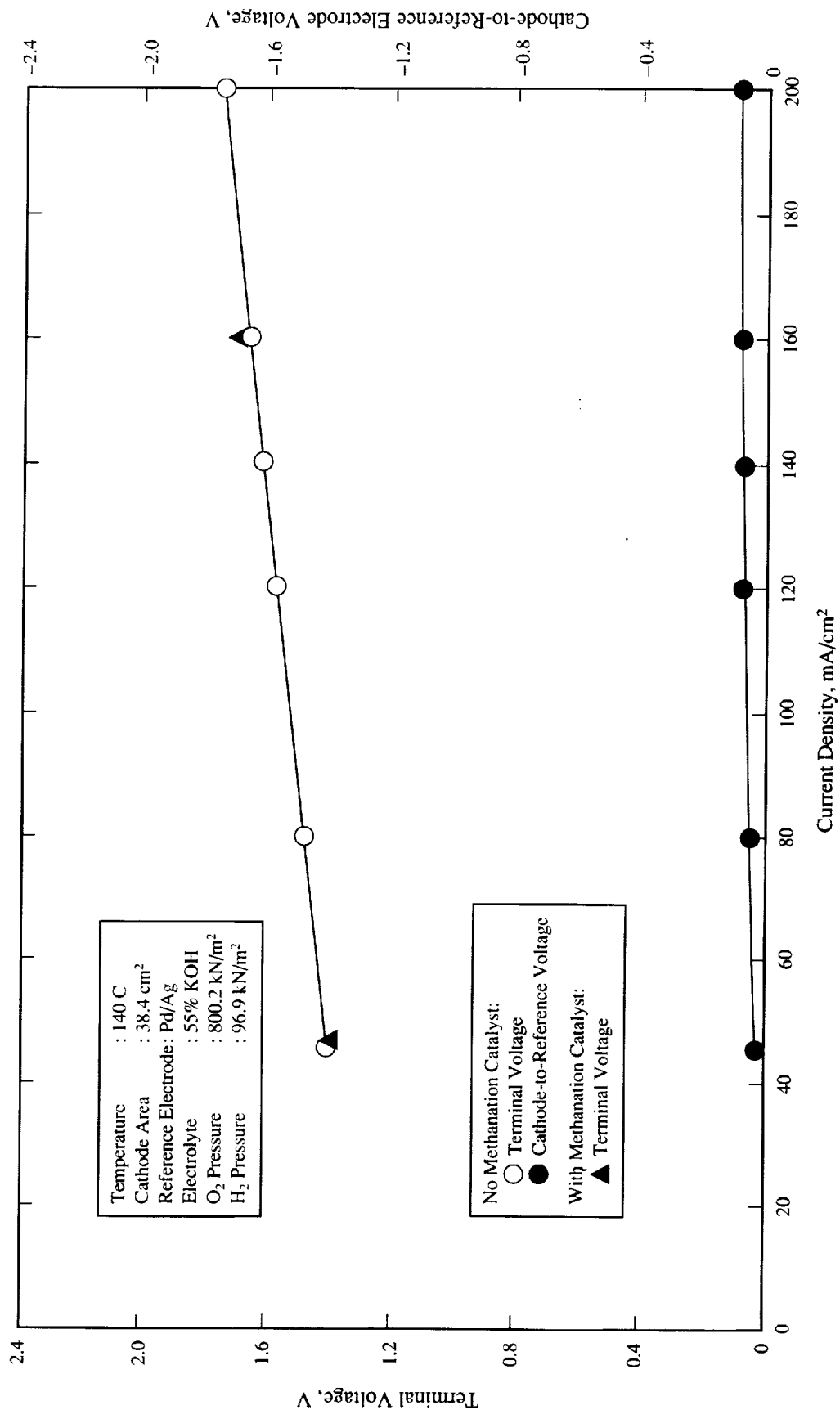


FIGURE 1-4 VOLTAGE AS A FUNCTION OF CURRENT DENSITY

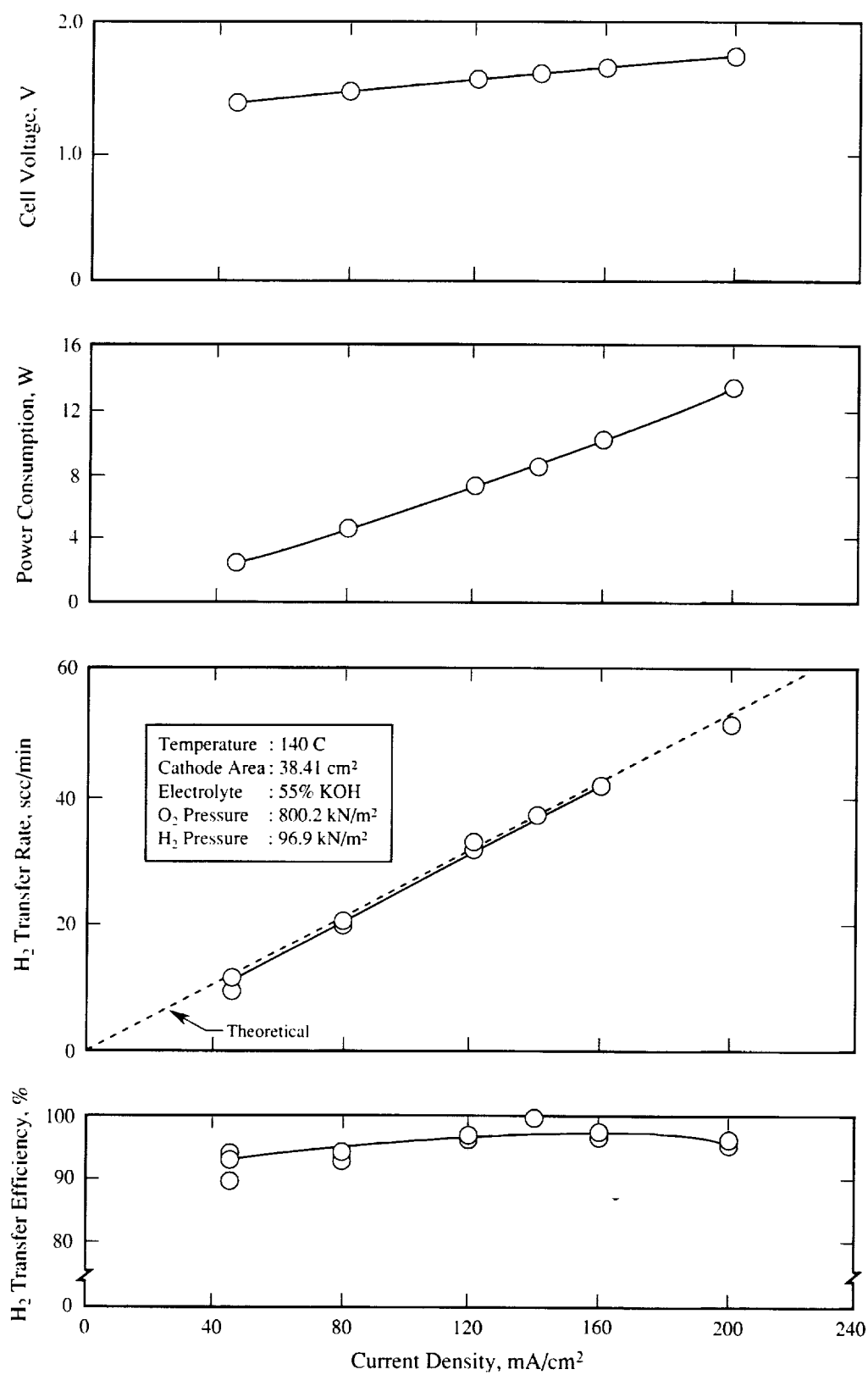


FIGURE 1-5 HYDROGEN TRANSFER CHARACTERIZATION

18.8 scc/min. This results in a molar ratio of  $H_2/CO_2$  of 2.5:1. No methane was detected by chromatographic analyses of the product gases.

Prior to the start of the parametric testing, the cathode was filled with the methanation catalyst. This catalyst is 20% ruthenium (Ru) on alumina extrudates (0.16 cm in diameter). The inner diameter of the SMC is 0.27 cm, so the catalyst extrudates had to be inserted coaxially in the SMC. The total weight of catalyst used in the Breadboard IORS is 1.47 g, and the length of the catalyst is 38.5 cm. The catalyst is retained in the cathode by plugs of Pyrex glass wool.

The presence of catalyst in the SMC does not affect its performance during the electrolyses of water, as shown by the two data points in Figure 1-4.

### 1.3 Parametric Testing

The parametric testing involves studies of the effects of temperature, reactant gas composition and flow rate on the performance of the Breadboard IORS.

#### 1.3.1 Temperature

Figure 1-6 shows the effects of temperature changes on the terminal voltage of the Breadboard IORS during the electrolysis of water. These data were obtained without  $CO_2$  flowing through the cathode. Data are provided for two current densities, 45.6 and 160 mA/cm<sup>2</sup>. The decrease in terminal voltage with increasing temperature is -2.3 mV/C and -3.7 mV/C, respectively, for the two current densities.

The effect of temperature changes on the methanation reaction was studied through testing of the Breadboard IORS and use of the mathematical model for the IORS. The Breadboard IORS was operated at the conditions listed in Table 1-1, and the conversion efficiencies of  $H_2$  and  $CO_2$  to  $CH_4$  were measured. The measured conversion efficiencies are compared in Figure 1-7 to the efficiencies calculated using the model. This figure shows excellent correlation of the performance predicted by the model and the actual performance of the Breadboard IORS over the range of operating parameters tested.

The effect of temperature on the performance of the Breadboard IORS, as predicted by the model, is presented in Figure 1-8. Curves are provided for inlet  $CO_2$  flow rates of from 2 to 20 scc/min.

#### 1.3.2 Reactant Gas Composition

The reduction of  $CO_2$  with  $H_2$  consumes four moles of  $H_2$  for every mole of  $CO_2$  that reacts. However, future space craft are expected to have less  $H_2$  available, so the methanation reaction will occur with a  $H_2/CO_2$  molar ratio of less than 4.0.

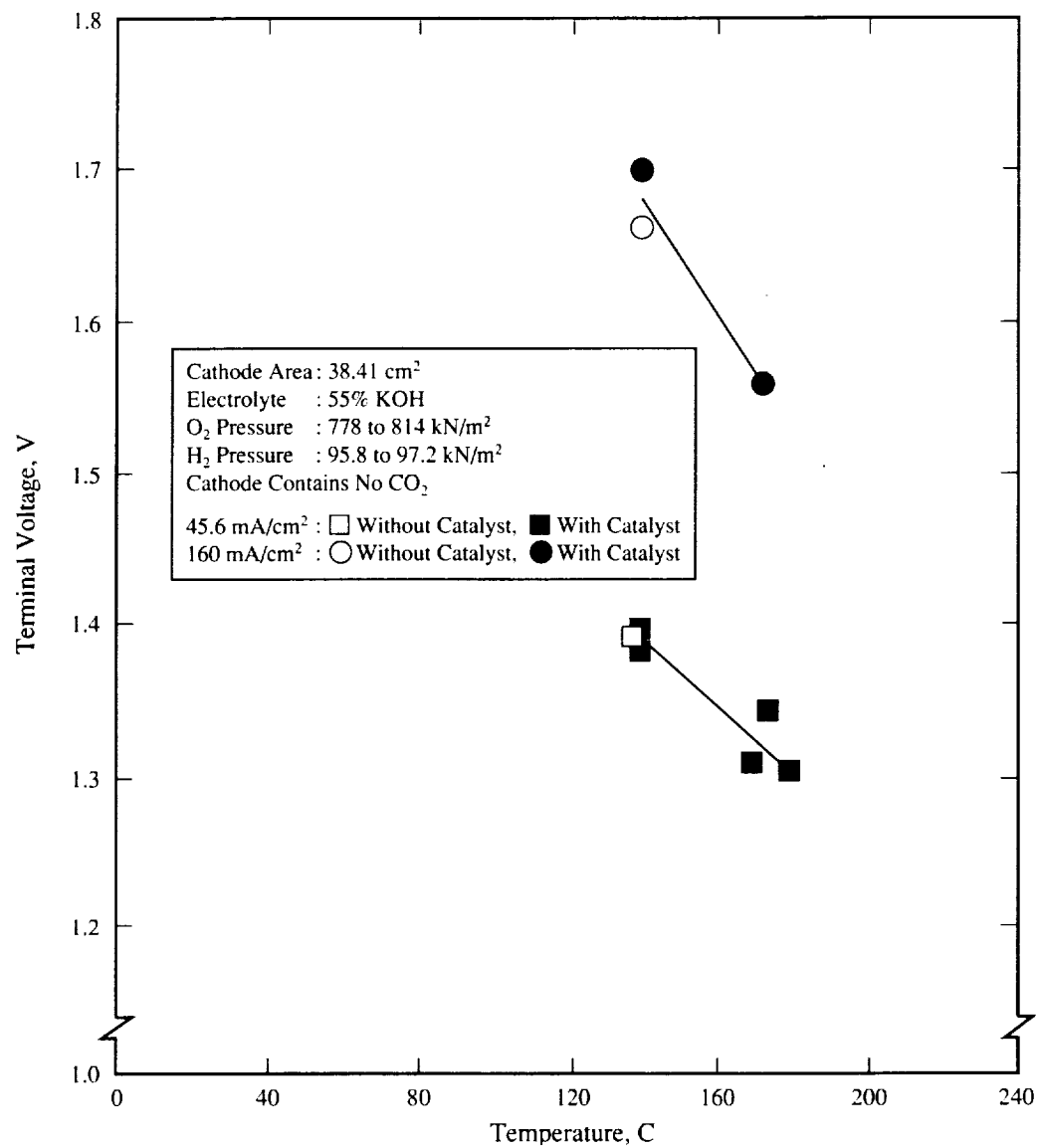


FIGURE 1-6 EFFECT OF TEMPERATURE ON ELECTROLYSIS VOLTAGE

TABLE 1-1 DATA FOR COMPARISON OF MEASURED AND  
CALCULATED CONVERSION EFFICIENCIES

Initial CO <sub>2</sub> Flow Rate, scc/min	H <sub>2</sub> /CO <sub>2</sub> Molar Ratio	Temp., C	Conversion Efficiency, % (a)			
			Hydrogen		Carbon Dioxide	
			Actual	Calculated	Actual	Calculated
19.1	2.05	141.1	10.4	11.2	5.33	5.81
18.6	2.11	142.8	10.4	11.7	5.48	6.16
10.1	3.88	142.8	10.7	13.4	10.4	13.0
7.96	4.37	144.4	10.8	15.7	11.8	17.2
2.03	20.0	144.4	9.4	13.3	46.8	66.5
24.0	1.59	145.0	10.6	11.6	4.23	4.60
10.5	3.40	172.2	32.0	26.7	27.4	22.7
1.14	8.41	176.1	47.5	47.6	100	100
5.95	1.89	177.2	72.3	60.4	34.2	28.5
6.26	1.57	177.2	74.7	62.7	29.4	24.6
6.47	2.98	177.2	48.4	46.8	36.1	34.9
6.76	3.08	177.2	45.3	44.6	34.9	34.3
6.61	3.60	177.8	40.6	41.7	36.5	37.5
6.80	3.49	177.8	41.1	41.6	35.9	36.3
2.90	8.60	177.8	37.4	39.7	80.4	85.4
3.47	2.88	178.3	71.7	67.5	51.7	48.6
2.69	4.34	178.9	67.8	64.0	73.6	69.4
2.32	5.26	178.9	63.1	62.0	83.1	81.6
3.80	3.11	178.9	63.9	63.3	49.8	49.2
3.70	3.20	178.3	64.5	63.0	51.8	50.4
1.71	6.19	178.9	62.2	63.3	96.4	97.9
3.89	3.43	185.0	68.8	62.2	59.0	53.3

(a) Catalyst = 0.76 cc of 20% Ru on Alumina. O<sub>2</sub> Pressure = 723 to 800 kN/m<sup>2</sup>. H<sub>2</sub> Pressure = 96 to 104 kN/m<sup>2</sup>.  
Electrolyte = 55% KOH.

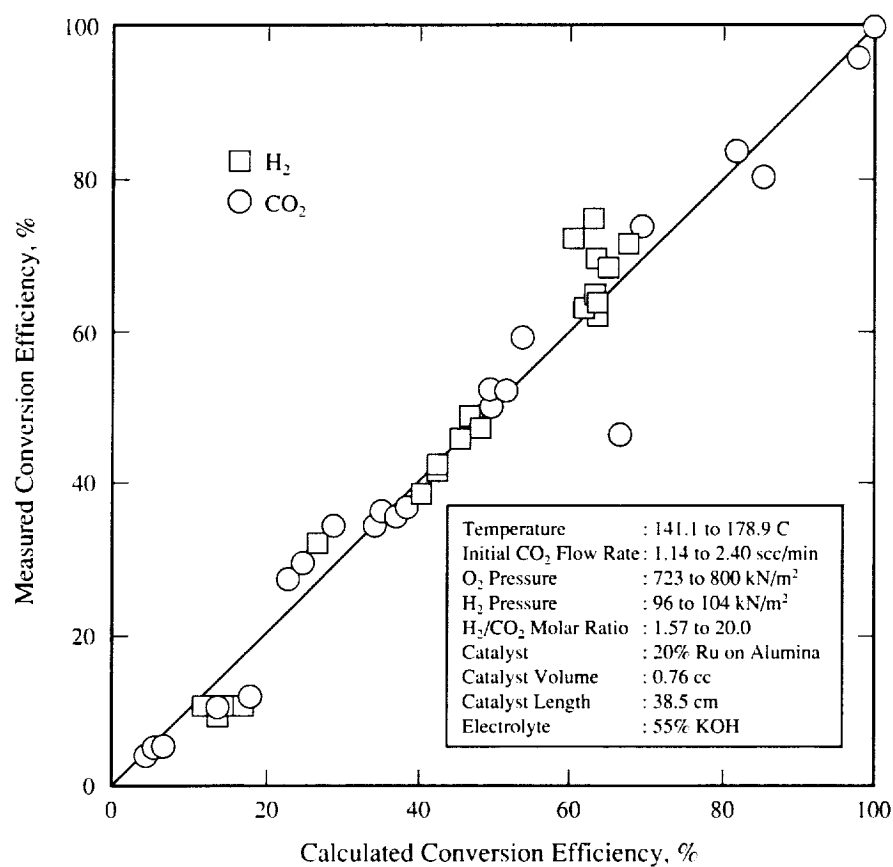


FIGURE 1-7 COMPARISON OF MEASURED AND CALCULATED CONVERSION EFFICIENCIES

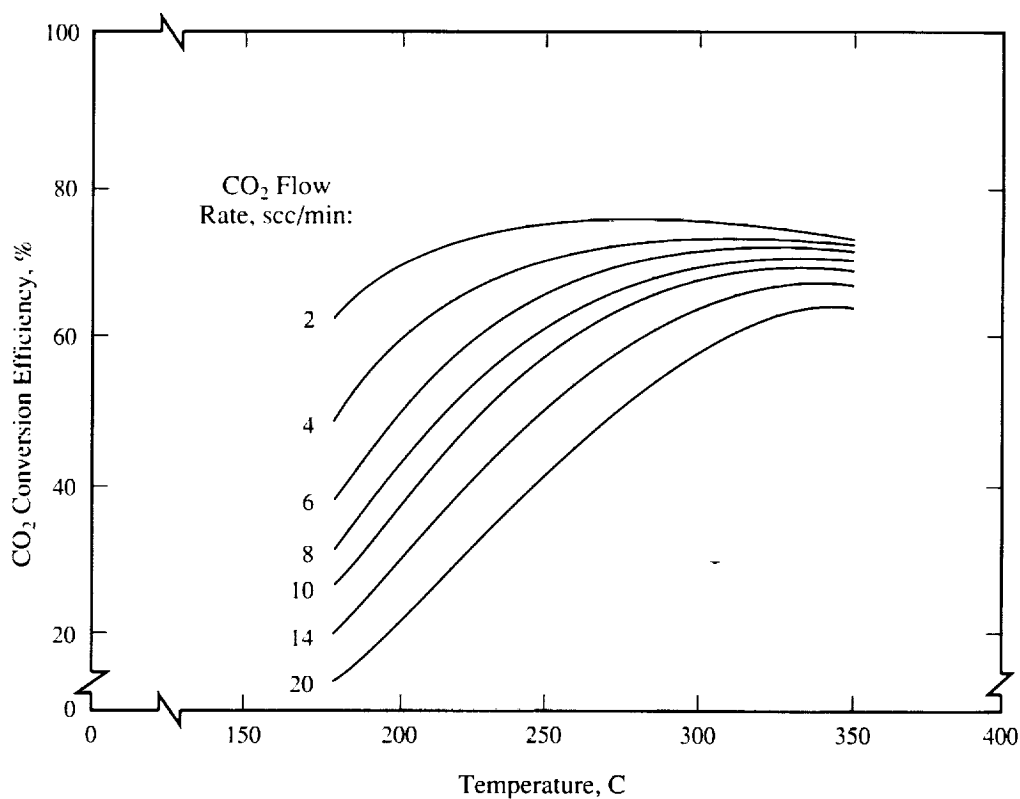
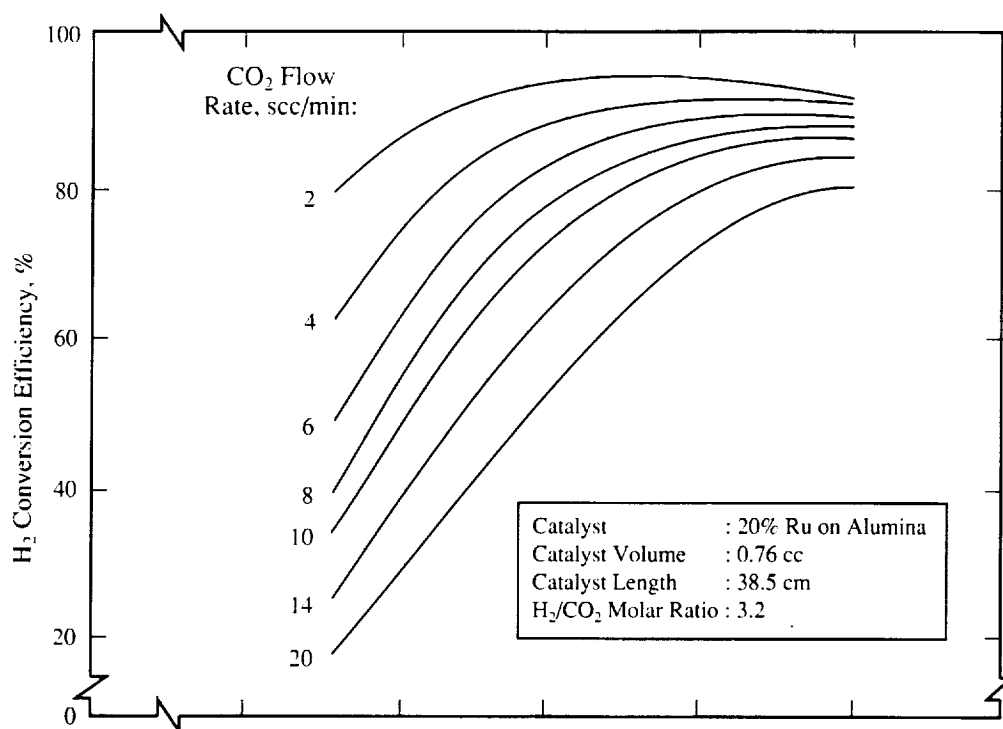


FIGURE 1-8 EFFECT OF TEMPERATURE ON METHANATION EFFICIENCY

To identify the molar ratio that may be expected in an end-item application, the specifications of Oxygen Generation Assembly (OGA) and the Carbon Dioxide Reduction Assembly (CReA) being developed for Space Station Freedom were reviewed. The OGA is to provide 4.65 kg O<sub>2</sub> per day during normal operation with a 4-person crew. The CReA is to process 4.0 kg CO<sub>2</sub> per day under normal (4-person) operating conditions. The CReA is to achieve 99% conversion of the lean feed constituent (i.e., H<sub>2</sub>). Both assemblies operate continuously.

With this information, the molar ratio anticipated in an end-item IORS, operating with a 4-person crew, was calculated to be 3.2:1, assuming 100% transfer efficiency of the H<sub>2</sub> through the cathode.

Figure 1-9 shows the effect of the molar ratio on the conversion efficiency of the Breadboard IORS operating at 178 C. These data show the conversion efficiencies for both H<sub>2</sub> and CO<sub>2</sub>. Data are shown for values of the initial flow rate of CO<sub>2</sub> into the Breadboard IORS from 2 to 20 scc/min.

### 1.3.3 Reactant Gas Flow Rate

As shown in Figure 1-8 there is a relationship between the flow rate of the gases and the efficiency of the conversion of the reactant gases to CH<sub>4</sub> and H<sub>2</sub>O. This is also shown in Figure 1-10 where the conversion rates of CO<sub>2</sub> and H<sub>2</sub> are shown as functions of the inlet flow rate of CO<sub>2</sub>.



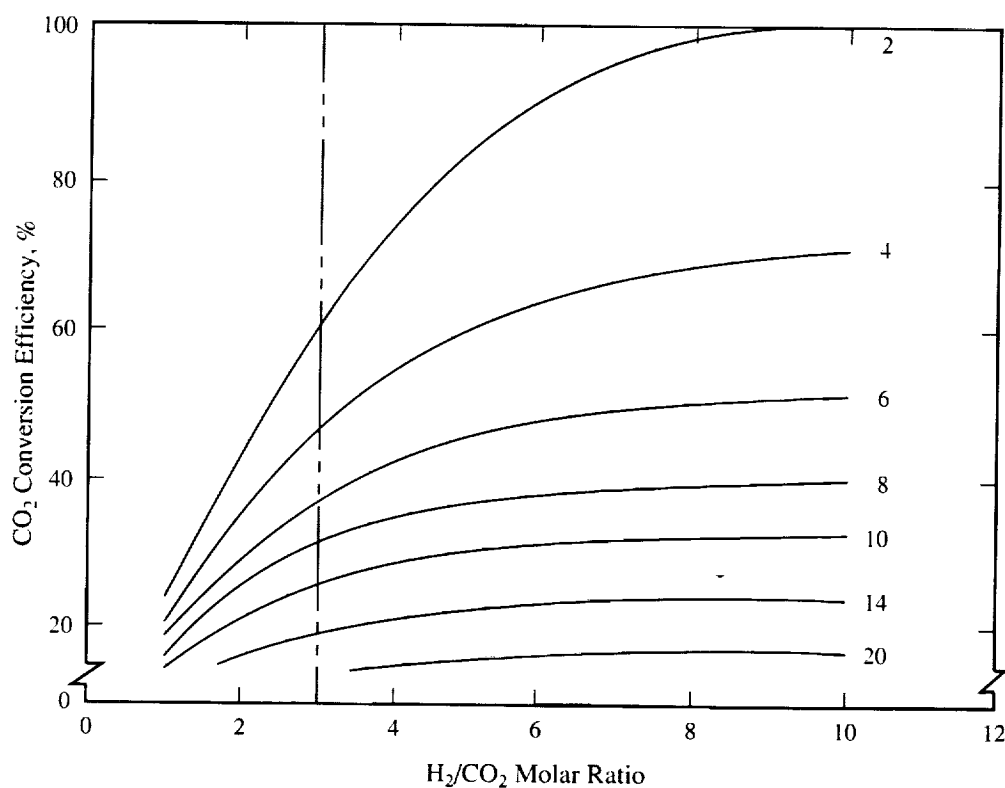
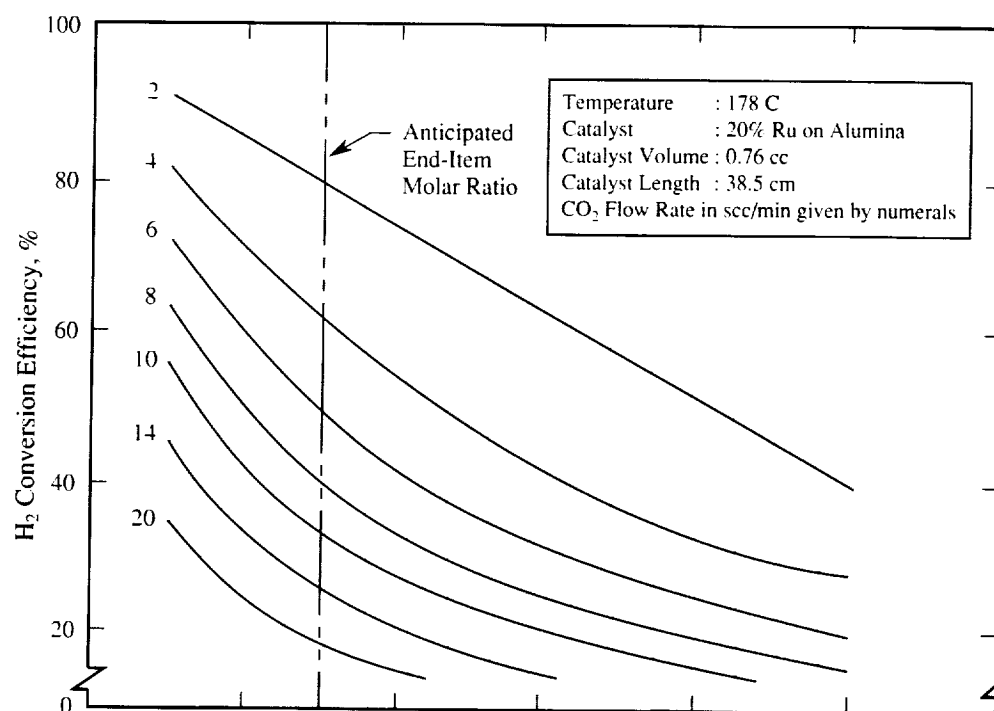


FIGURE 1-9 EFFECT OF REACTANT GAS COMPOSITION  
ON METHANATION EFFICIENCY

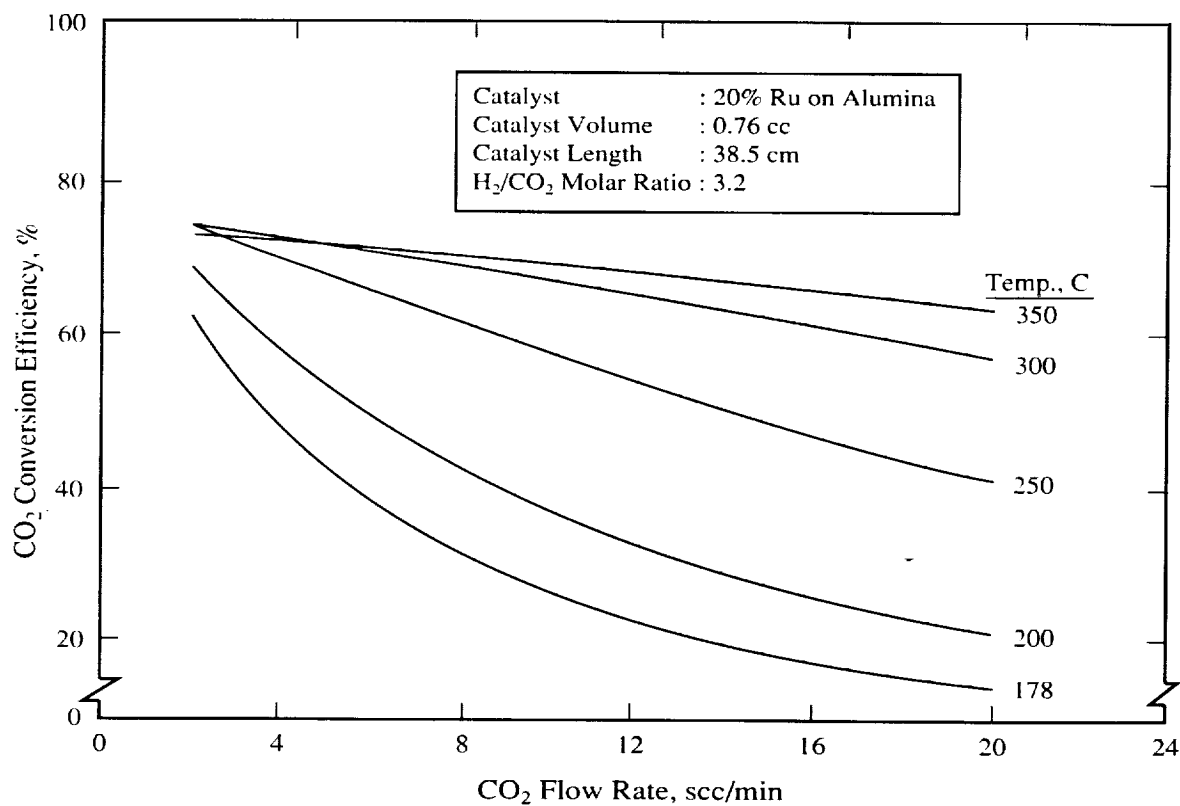
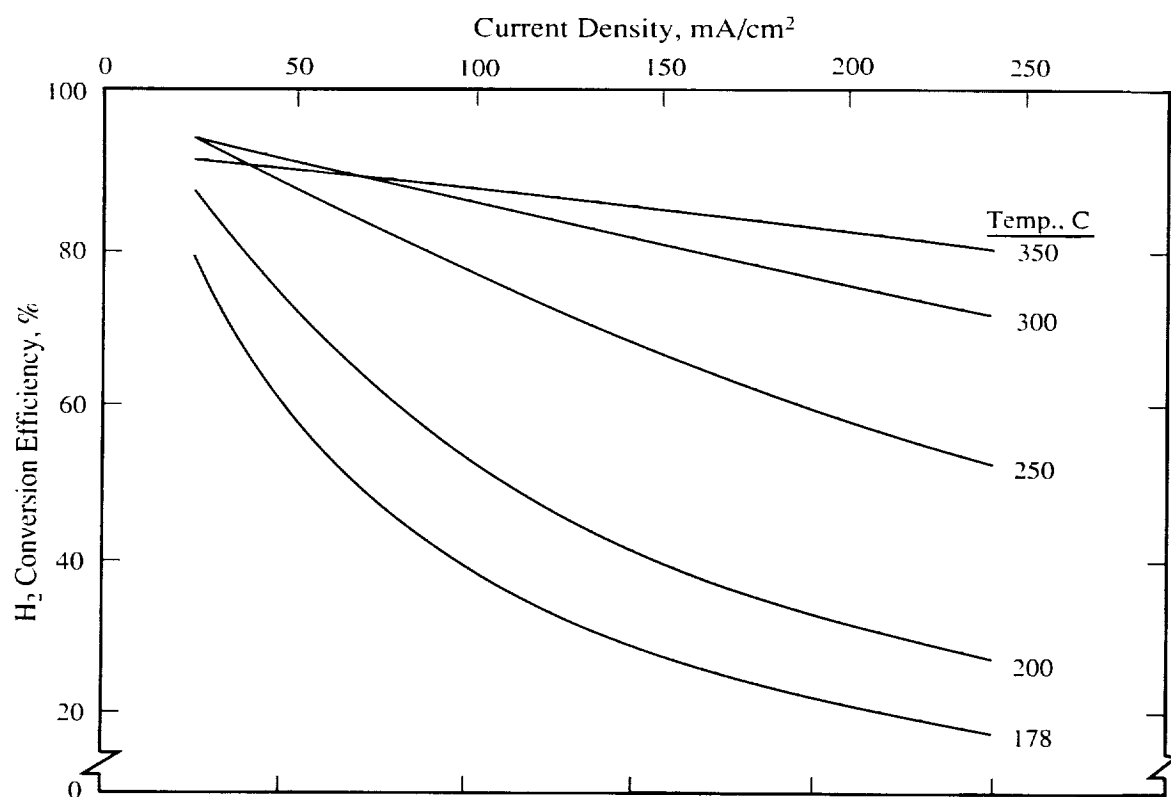


FIGURE 1-10 EFFECT OF INLET CO<sub>2</sub> FLOW RATE  
ON METHANATION EFFICIENCY

## 2.0 PROBLEMS

No problems have been encountered which may impede performance or impact program schedule or cost.

3.0 WORK TO BE PERFORMED NEXT REPORTING PERIOD

The parametric tests will be completed during the next reporting period. Based on the analysis of those results and the results summarized here, the preliminary process design of a 4-person IORS will be developed. The preliminary mathematical models presented in the prior Bimonthly Technical Progress Report (TR-1619-1-1) will be updated if necessary. Also, the Final Report will be prepared and submitted on or before 07/08/93.

4.0 COST STATUS

The status of the program's cost is summarized below, as required by Attachment J-2 of Contract No. NAS8-39843.

1.	Total cumulative costs as of 04/30/93:	\$35,200
2.	Estimated cost to complete contract:	\$14,800
3.	Estimated percentage of work completed:	70.4%

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
<small>Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204 Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.</small>				
1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE 07 May 93	3. REPORT TYPE AND DATES COVERED Bimonthly Technical Progress Rpt. 09 Mar 93-07 May 93	
4. TITLE AND SUBTITLE  Integrated Oxygen Recovery System Technical Progress Report No. 2			5. FUNDING NUMBERS  NAS8-39843	
6. AUTHOR(S)  Dr. M. Gene Lee and Dr. Ronald J. Davenport				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)  Life Systems, Inc. 24755 Highpoint Road Cleveland, OH 44122			8. PERFORMING ORGANIZATION REPORT NUMBER  TR-1619-1-2	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)  National Aeronautics and Space Administration George C. Marshall Space Flight Center Marshall Space Flight Center, AL 35812			10. SPONSORING/MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES				
12a. DISTRIBUTION/AVAILABILITY STATEMENT			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words)  Life Systems has conceptualized an innovative Integrated Oxygen Recovery System (IORS) applicable to advanced mission air revitalization. The IORS provides the capability to electrochemically generate metabolic oxygen (O <sub>2</sub> ) and recover O <sub>2</sub> from the space habitat atmosphere via a carbon dioxide (CO <sub>2</sub> ) reduction process within a single assembly. To achieve this capability, the IORS utilizes a novel Solid Metal Cathode (SMC) water electrolysis unit that simultaneously serves as the Sabatier CO <sub>2</sub> reduction reactor. The IORS enables two major life support systems currently baselined in closed loop air revitalization systems to be combined into one smaller, less complex system. This concept reduces fluidic and electrical interface requirements and eliminates a hydrogen (H <sub>2</sub> ) interface.  Life Systems is performing an evaluation of the IORS process directed at demonstrating performance and quantifying key physical characteristics including power, weight and volume. In this report, the results of the checkout, shakedown and initial parametric tests are summarized.				
14. SUBJECT TERMS  Oxygen, carbon dioxide, reduction, hydrogen, electrochemical Solid Metal Cathode, air revitalization, methanation, Sabatier			15. NUMBER OF PAGES 22	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT  Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE  Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT  Unclassified	20. LIMITATION OF ABSTRACT  UL	